2.2 AN UNUSUAL ICING CASE: 20 MARCH 2000, DENVER, COLORADO

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1. INTRODUCTION

On 20 March 2000, inflight icing conditions in the Denver International Airport (DEN) terminal area were adverse enough to cause airport operations to come to a standstill for several hours. Aircraft arrived at Denver heavily iced, causing delays due to difficulties removing this ice prior to their turn-around and subsequent takeoff. A SIGMET was issued for severe icing conditions over the area. Several airlines decided to cease operations at DEN while waiting for these conditions to abate.

United Air Lines, the airline with the most flights in and out of DEN, cancelled all arrivals and departures between 1700 and 2030 UTC (all times are UTC). In all, 159 outbound and 140 inbound flights were cancelled. Air Wisconsin, which flies mainly Dornier 328 and BAE-146 aircraft, cancelled 152 flights due to weather. Thus operations were severely disrupted for both a large air carrier and a smaller commuter airline due to this icing situation. It is highly unusual for inflight icing conditions to affect airport and airline operations to this extent. This paper will describe those effects as well as products being designed to mitigate them in the future.

2. RESULTS OF A QUESTIONNAIRE

Several days after the event, Air Wisconsin distributed a questionnaire to their pilots flying in and out of DEN. Thirty-one pilots responded, four of whom did not fly due to flight cancellations. What follows are some of the questions and answers:

When did the heavy buildup of ice occur? *Descent - 15, low altitude maneuvering - 13*
At what altitude did this occur? *Summary: from the surface (~5000 ft) to 15,000 ft, centered on 9000 ft with half the observations from 8,000 - 10,000 ft. (Note - all heights are MSL)*
Which arrival gate(s) were most impacted? *All*
Would a different altitude or descent profile help mitigate ice buildup? *Positive - 5, negative - 15*

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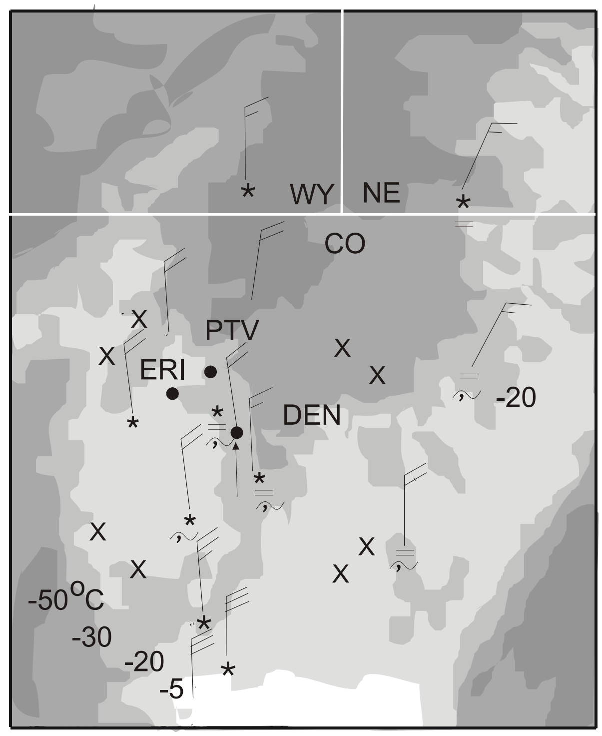

Fig. 1 The area around Denver International Airport (DEN) with METARS wind directions and precipitation type at 1800. Instrument sites discussed in the paper are indictated as are DEN arrival gates (X). The background is the 1745 IR satellite image; cloud top temperatures (°C) are shown on contours in bottom left. Arrow south of DEN shows approximate runway 35L/R approaches extended to 30 km.

Was icing confined to unprotected surfaces? *Yes – 13, no – 11*
Would a different altitude or descent profile help mitigate ice buildup? *Positive - 5, negative - 15.*
Did the weather reports you received in your weather packages adequately describe or predict this icing prior to it actually happening? *Yes - 6 no - 20 (Note - it is not known what products were included in the weather packages that day.)*
Was March 20th an extremely unusual event for DEN? *Yes - 23 no - 3*
Anything else that you would like to share or feel is important? *Selected comments are used to introduce the following sections of the paper.*

3. WEATHER

"Freezing rain presence resulted in cessation of our flight ops for a period of time. Was it caused by an inversion aloft and if so, what were the associated weather conditions?"

At approximately 1000, 20 March, a cold front moved into northeastern Colorado. Temperatures in the area steadily dropped during the morning, for example, from 8oC at 0600 to -2^{o}C at 1600 at DEN. Northeasterly flow created an upslope cloud; ceilings dropped to <1000 ft AGL reported at ~1100 (ft are used throughout since this is what aircraft and aircraft products use). Freezing drizzle and freezing rain (FZDZ and FZRA) were reported at the surface in northeastern CO beginning ~1600. Since the entire atmosphere was <0^{o}C, the freezing precipitation did not result from melting of snow in a warm layer aloft; it had to be produced through a collision-coalescence process. Note that ASOS is not capable of directly detecting FZDZ; it is sometimes misreported as FZRA and often goes unreported unless the METAR is manually augmented (Ramsay and Dover, 2000).

The NOAA Environmental Technology Laboratory operated their MMCR package (a millimeter-wave cloud radar and dual-channel radiometer, see Martner et al., 2002) at Erie, CO (ERI) during this event. NOAA also operated a 404-MHz wind profiler at Platteville (PTV, see Fig. 1 for location).

The 1200, 20 March sounding from DEN indicated saturated air from nearly the surface to the tropopause (not shown). At 500 hPa, a strong short wave dug southeastward from the Pacific Northwest. By 1200 it had established a deep trough over the western states, with southwesterly flow over Colorado (as in Fig. 2).

Low-level upslope flow created a cloudy layer to ~11,000 ft MSL (Fig. 2), with light precipitation, including a mix of snow and FZDZ reported at DEN from 1620 - 1908, then turning to snow. Some patchy upper-level clouds were also present. These began to precipitate snow into the lower cloud around 1900, when cloud top temperatures began to reach values <16^{o}C approximately. Integrated liquid water amounts measured by the ERI radiometer ranged from ~0.4 - 0.9 mm until 1930 (Fig. 3). A sharp decrease then occurred as the upper cloud layer precipitation fell into the lower cloud layer, also increasing reflectivity (Figs. 3 and 4). This strongly suggests that falling snow removed supercooled liquid water from the lower cloud layer (as in Politovich and Bernstein, 1995). An analysis of hydrometeor type applied to the MMCR reflectivity and velocity data (Fig. 4, based on Martner and Schneider, 2001), shows good agreement with the surface observations and supports these conclusions.

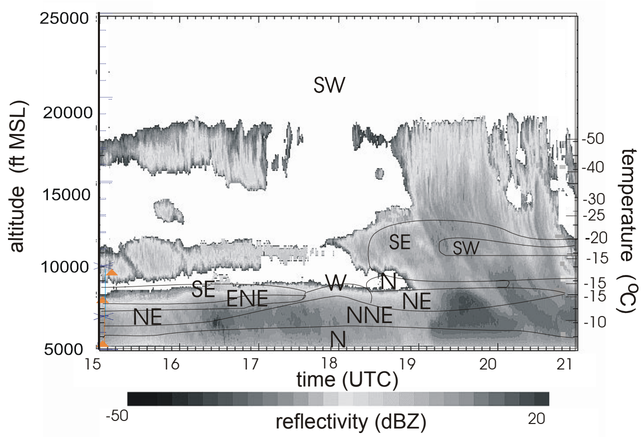

Fig. 2. MMCR reflectivity at ERI with PTV profiler wind directions superimposed. Temperatures from the 2400, 20 March DEN sounding are shown on the right. Note several inversions around –15^{o}C.

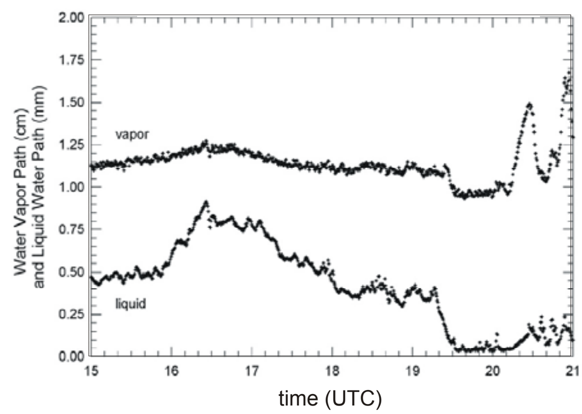

Fig. 3. Vertically-integrated water vapor and liquid water from the NOAA dual-channel radiometer at ERI.

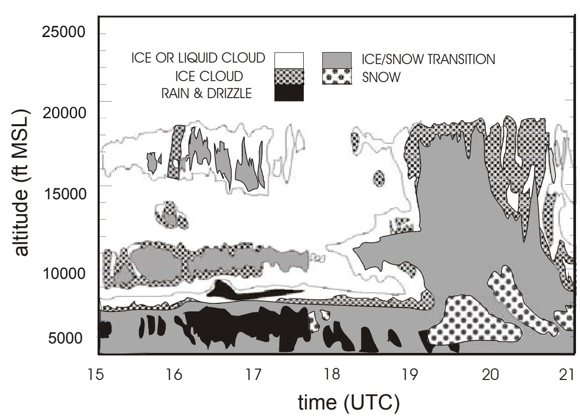

Fig. 4: Hydrometeor type derived from MMCR reflectivity and velocity data.

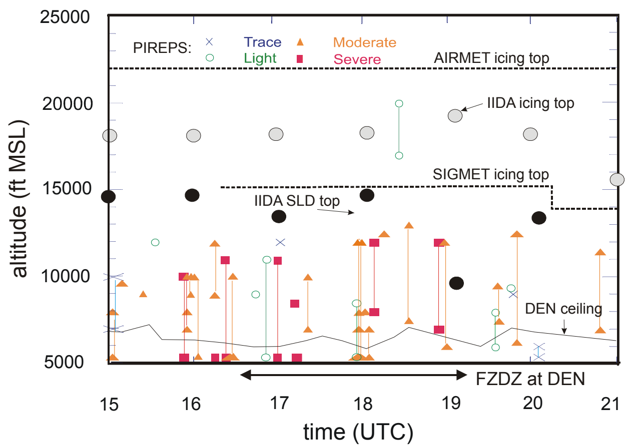

Fig 5: Icing PIREPs from the DEN area. Lines extend from top to base of icing report, those labeled "surface" or just "below altitude" are extended to 5000 ft in this figure. Other features are as indicated.

6. AVAILABLE ICING WARNINGS

"Ice was reported or forecast but PIREPs later were more helpful...I came in from the southwest and had about 4" total accumulation "

The Aviation Weather Center issued a series of AIRMETs for icing covering a large portion of the High Plains and Rocky Mountain region. The AIRMETs called for occasional moderate rime and mixed icing in cloud and precipitation from the freezing level to 20,000 ft (raised to 22,000 ft at 1445, see Fig. 5). In response to numerous severe icing PIREPs, a SIGMET was issued at 1615, valid until 2015, for much of the Front Range of the Rocky Mountains in CO and WY. The SIGMET was for occasional severe rime and mixed icing in cloud and in precipitation below 15,000 ft. Pilot reports (PIREPs) of icing were frequent in the DEN area throughout the episode, with many moderate and several severe reports (Fig. 5). PIREP altitudes were generally well below the AIRMET icing top altitude; all but one were below 13,000 ft.

Output from the Integrated Icing Diagnosis Algorithm (IIDA, McDonough and Bernstein, 1999) was available as an experimental product to Air Wisconsin. IIDA showed icing tops over DEN around 19,000 ft during the 1500 - 2100 time period shown in the figures (Fig. 5, the 0.25 icing potential is used for the grid point centered just to the south of DEN, where the approach route resides). Starting at 1500, IIDA diagnosed a potential for supercooled large droplet icing over the DEN area, at altitudes ranging between <8,000 to nearly 15,000 ft. This type of icing includes FZDZ and FZRA, which are conditions for which no aircraft are certified for flight.

7. OPERATIONS

"Once freezing drizzle was reported, we suspended DO 328 operations to DEN."

An Air Wisconsin DO 328 aircraft carrying 25 people ran off runway 35L while landing at about 1430 after a flight from Bismarck, ND. No one was hurt, but the incident closed 35L for about five hours. This forced aircraft to use runway 35R rather than both 35R and 35L. Possibly as a result, aircraft started the approach farther south, were spaced farther apart, and were requested to keep airspeed down. This could have contributed to a longer flight duration in the icing condition, as the approach path is below the ~11,000 ft cloud tops. Also, flying slower increases time in cloud and can also tend to expose more aircraft surface to icing.

United Airlines canceled all arriving and departing lights from 1700 to 2030 due to heavy ice buildup on arriving aircraft. The airline resumed a reduced schedule in the afternoon, but the delays effected flights across the United States throughout the day. American Delta, Continental and other air carriers canceled additional flights. No flights were cancelled by Frontier Airlines, but their departures were running up to 90 min late. Air Wisconsin's cancellations were also substantial as mentioned above. (Nicholson and Lieb, 2000).

8. PRODUCT IMPROVEMENTS

"DEN approach vectored us downwind for the ILS 35L <FL140, which put us in the ice for a long downwind and extended final.... being kept high would have helped - but we had no notice of what we would be getting into."

It is clear from Fig. 1 that aircraft entering the DEN terminal area through any of the arrival gates and routed to the south were forced to encounter the lower, warmer cloud that contained the icing hazard. It may be the case that keeping aircraft higher, above 13,000 ft, and out of cloud as long as possible before final descent for landing would have helped alleviate an icing problem. Bringing aircraft down quickly and placing them below cloud base would not have worked, since icing was reported in freezing drizzle nearly all the way to the surface. How would dispatch or air traffic control personnel have known this?

The IIDA can be presented in a plan view or vertical cross-section along a flight path. Figure 6 shows an example of this product for 1600, 20 March 2000, along a path from Sheridan, WY (SHR) through DEN to Colorado Springs, CO (COS). The icing potential field extends to nearly 20,000 ft, and has higher values near and to the south of DEN. The field more relevant to this case is SLD potential, which indicates a high potential (>0.7) to 10,000 ft and lower values to 16,000 ft. The greatest area of SLD potential is south of DEN. The SLD field flags areas aircraft should avoid.

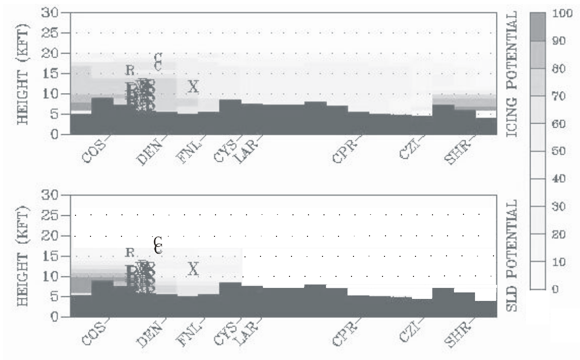

Fig. 6: IIDA south-to-north cross section of icing and SLD potential from COS through DEN to SHR for 1600, 20 March 2002. Terrain is indicated by solid black shading. PIREPs are in text (R=rime, C=clear, X=mixed icing type, and larger symbols are higher severity).

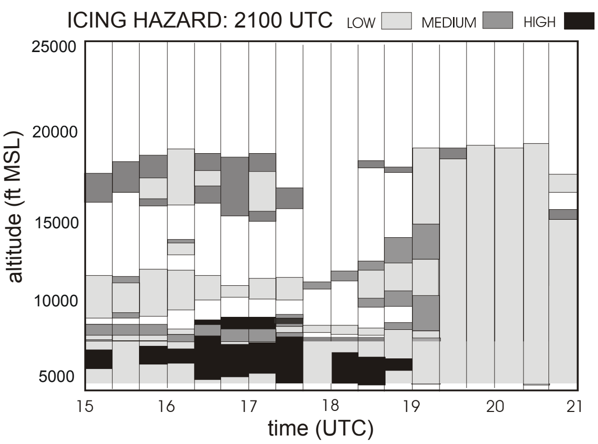

Fig. 7: Simulated icing product from GRIDS. Data are reformatted from Fig. 4 (MMCR).

IIDA is currently available hourly at a horizontal resolution of 40 km. For a terminal-area product, higher resolution both in time and space is desired. Additional information beyond the model, METAR, satellite, NEXRAD and PIREP data is probably needed to achieve this goal.

There is also potential for icing detection product meant to cover the relatively small terminal area. The data from remote sensors such as the NOAA Ground Remote Icing Detection System (GRIDS, Reinking et al., 2001) being proposed could provide warnings of hazardous icing conditions in a terminal area. A preliminary example of such a product is provided by the MMCR package data. The hydrometeor types shown in Fig. 4 were altered to produce Fig. 7. Time resolution was changed to 20 min to represent realistic monitoring and reaction times on the part of air traffic and dispatch staff. The hydrometeor types were changed to reflect their potential icing hazard: ice and snow and the ice/snow transition are labeled "low", ice/liquid cloud "medium", and freezing rain and drizzle "high". This provides a simpler presentation of information that a busy airspace decision-maker could readily convey to the pilot.

9. SUMMARY

"In ~5 years of Denver flying, this has happened only twice (ice this bad). Forecast was for big winter storm/snow, but this usually doesn't bring this much icing!"

20 March, 2000 presented an unusual situation for Denver International Airport: hazardous inflight icing conditions adversely affected operations for at least two commercial air carriers. Development of new products and dissemination to pilots and air traffic controllers could lessen the effects of such severe icing in the future.

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